International Journal of Computer Information Systems and Industrial Management Applications
ISSN 2150-7988 Volume 18(21s) 2026 pp. 1387-1397
https://doi.org/10.70917/ijcisim-2026-5400
Article

# A Novels Pilot based Channel Estimation Technique using OFDM in Vehicular Communication

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**Abstract:** An OFDM system was needed for WAVE. Reliable Channel Estimation is important for proper system performance in VANET especially with time varying characteristics of the channel in V2V communication. A new method has been suggested in which the pilots are optimally inserted into the OFDM band. It is known as FCPCE. The simulator results and real core measurements validate that the proposed method is efficient as compared to other similar methods in terms of QOS.
**Keywords:** Intelligent Transport Systems, VANET, OFDM, IEEE 802.11p, Channel Estimation, Pilot Symbols, Vehicular Communication.

## 1. Introduction

ITS allow communication between the transport infrastructure and vehicles to enhance road safety, traffic management and convenience for the driver. The VANETs is one of the key enablers in ITS to provide real-time information exchange between the vehicle and the roadside devices [1,11]. Therefore, reliable communication plays a significant role in the efficient working of the vehicular communication systems.

The multipath propagation, high mobility and fast channel fluctuations are the major challenges for wireless communications in automotive environment that can lead to impairment of the signal and reduction of communication performance [8,13]. Accurate channel estimate techniques are required to overcome these challenges, and effectively identify the signal at the receiver.

Because of its immunity to frequency selective fading and the high spectral efficiency, the OFDM has been widely used in the modern wireless communication systems [5,16]. However, OFDM systems are quite sensitive to the inter-symbol interference and channel variations, especially in fast dynamic vehicle situations [3].

The IEEE 802.11p standard was meant to be for V2V and V2I communication in ITS applications [4,6,12]. For such systems the channel parameters are usually estimated by inserting known reference symbols within the transmitted signal by means of pilot-based channel estimation algorithms .

In this paper, FCPCE for vehicle communication in 5 GHz band is considered. The proposed method will be used to improve the accuracy of the channel estimation in fast varying vehicular channels.

## 2. Related Work

Because of their potential to enhance transportation safety and effectiveness, vehicular communication and ITS have received a lot of attention in research. Several research have evaluated the performance of IEEE 802.11p based vehicle communication systems in different environmental situations [12].

However, the channel estimation approaches have been extensively studied in OFDM systems. Coleri et al. [5] analysed the pilot based channel estimate methods and proved their efficiency in increasing the system performance. A channel estimation method for multipath channels was proposed by Edfors et al [16] using SVD.

To improve the estimation accuracy, Lin and Lin [7] suggested one channel estimation method for IEEE 802.11p system based on least-squares algorithm by employing Zadoff-Chu sequences. Measurement based studies for characterizations of vehicle communication channels and for the study of the impact of mobility on channel performance have also been performed [17,18].

The effect of environmental factors like traffic density, urban infrastructure etc. has been also confirmed by experiments on the dependability of vehicular communications [10,12]. These investigations emphasise the need for effective channel estimate strategies to ensure reliable communication in highly dynamic vehicle situations.

## 3. Statement of the problem

The summary of the research done so far suggests that they were either experimental or theoretical in approach. No study has been done in comparison between both of the features. In this case, a detailed performance assessment is crucial to improve vehicular communication. For instance, the research efforts on enhancement of DSRC/WAVE performance did not include any real case activation; the fundamental argument of this research endeavor is that all the practical events should be incorporated to check the performance.

## 4. System Model

### *A. Structure of Physical Layer*

PHY (Physical Layer): An interface between MAC Layer and media for transmitting/receiving frames. This layer comprises hardware specification, bits conversion, and signal encoding and data formatting. As seen in the Fig. 1, PHY has two sub layers PLCP which is used to communicate with MAC layer and PMD which acts as an interface to the radio channels and fibre link.

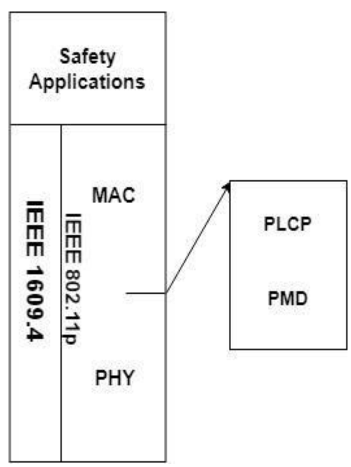


Figure 1. WAVE protocol stacks and sub layers of PHY

The PLCP converts the PDU from the MAC layer into an OFDM frame and the PMD does the data encoding and modulation. The PPDU which consists of a preamble, a signal field and a payload part is shown in Fig.2. TO obtain CSI training OFDM symbols or pilot symbols are inserted in each OFDM symbol. The main applications of the pilot symbols are channel estimation and transmission error correction. The main idea is to insert some well known symbols (often , amplitude and phase are known) between the subcarriers such that all the deviates may be adjusted at the time of demodulation. The number of pilots is channel dependent.

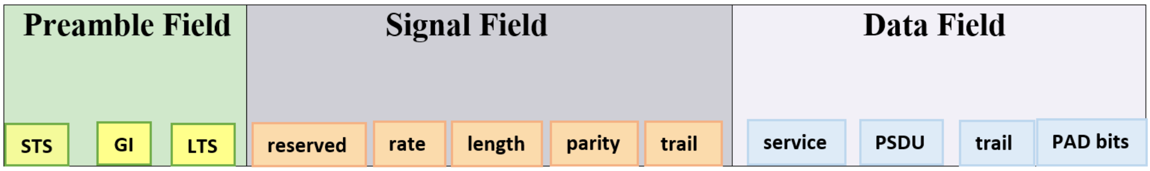


Figure 2. IEEE 802.11p PHY PPDU frame structure

Transmitter during a start of transmission of the OFDM preambles. Pilot symbols are complex exponential in time, and placed in each OFDM symbol so that they are distinguishable from information symbols in the frequency domain. However, in the case that the channel does not change much for a large number of OFDM symbols, the channel estimation by training of OFDM symbols may be enough for symbol detection. However, with time-varying channels, it is desired to send training OFDM symbols frequently to get good channel estimates for detection.

### *B. Physical Layer Data Transmission Model*

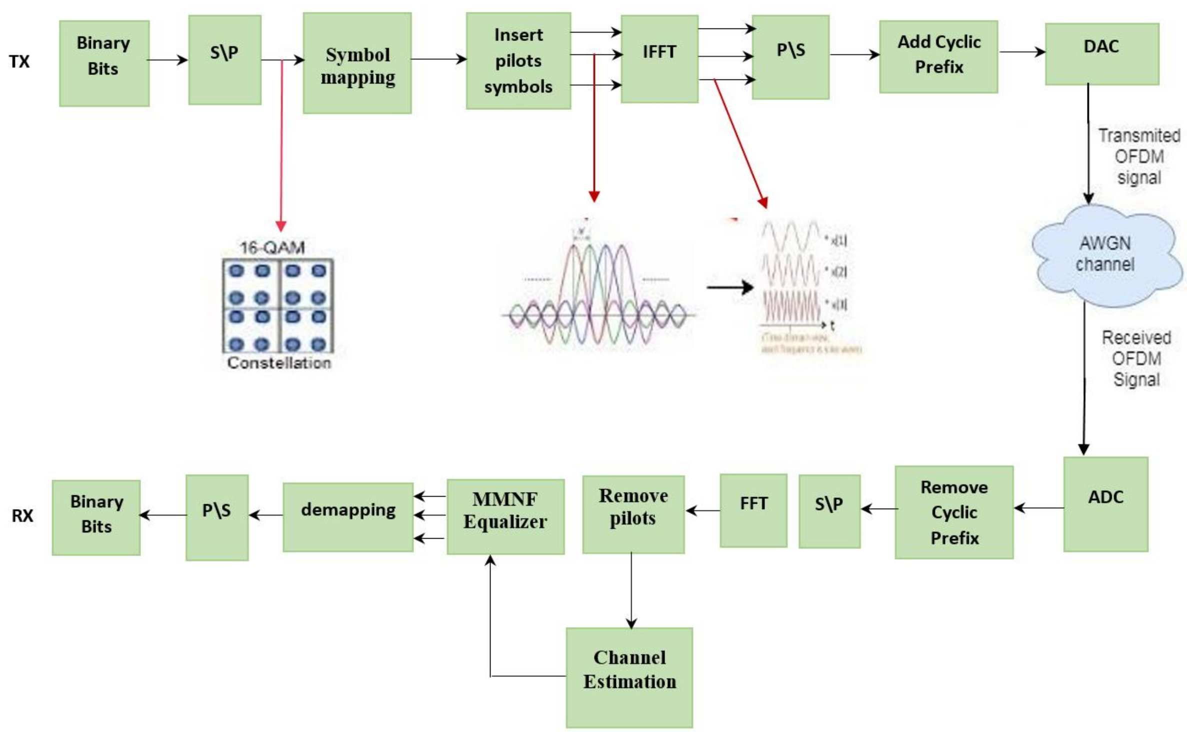


Figure 3. Proposed OFDM channel model

The OFDM communication channel model of the proposed system is shown in Fig. 3. The following steps provide an overview of the procedure between the transmitter and the receiver.

Step 1: Transmit a signal (TX):

1. Create random data.
2. The S-to-P conversion is a process that converts a serial signal into a parallel signal.
3. Using different modulations like: BPSK, QPSK, 16QAM, 64QAM.
4. Let the Pilots on.
5. IFFT (N = 64).
6. Cyclic Prefix is added and parallel to serial conversion is done.
7. Finally, the signal is converted to digital to analogue which is then represented as:

But IFFT blocks are used to transform the data length N {X (k)} to the time domain signal {x (n)} as:

$$x(n) = IFFT\{X(k)\},\ n = 0,1,2,\dots,N-1$$

$$x(n) = \sum_{k=0}^{N-1} X(k)\, e^{j\left(\frac{2\pi kn}{N}\right)} \qquad (1)$$

Step 2: where N is the length of IFFT. The guard interval is chosen to be greater than the delay spread and the Doppler shift. Cyclic prefix is part of the OFDM symbol in the process of inter symbol interference removal. The OFDM sign provides:

$$x_f(n) = \begin{cases} x(N+n), & n = -N_{g,} - N_g + 1, \dots\dots, -1 \\ x(n)\quad, & n = 0,1,\dots\dots\dots, N-1 \end{cases} \qquad (2)$$

What is the width of guard band, Ng? It is assumed that the channel is a frequency selective and time variable Rayleigh fading channel, and it is wanted to transmit the OFDM symbol x f (n) across the channel.

Step 3: On receiver (RX)

1. FCPCE is a technique of reconstructing the broadcast signal from the received signal.
2. The received signal is: The input signal and the channel coefficient are convolved to get the received signal:

$$y_f(n) = x_f(n) \otimes h(n) + w(n) \qquad (3)$$

Where, w(n) is AWGN.

Step 4: S/P block has its input as the received signal, the guard bands are removed and the expression for Y(n) is:

$$y_f(n)\ \ for\ \ -N_g \le n \le N-1$$

$$Y(n) = y_f(n + N_g),\ n = 0,1,2,\dots,N-1 \qquad (4)$$

If that is the case, Y(n) will be traveling towards the FFT and will be equal to:

$$Y(k) = FFT\{y(n)\},\ k = 0,1,2,\dots,N-1$$

$$Y(k) = \sum_{n=0}^{N-1} y(n)\, e^{-j\left(\frac{2\pi kn}{N}\right)} \qquad (5)$$

Without ISI the signal is sent. The relation between the resultant Y ( k ) = FFT { y ( n ) } is given by ..

$$Y(k) = X(k)H(k) + I(k) + W(k) \qquad (6)$$

Where, I(k) is the inter symbol interference (ISI) due to preceding sent signal. The pilot signals pass through the FFT blocks, the pilot signals are then removed and the channel coefficient H (k) is estimated. Then actual signal Y(k) transmitted is calculated by FCPCE method.

$$X(k) = \frac{Y(k)}{H(k)},\ k = 0,1,2,\dots,N-1 \qquad (7)$$

Lastly, the information is recovered by the signal demodulation.

## *C. Packet Structure Generation*

IEEE 802.11p is based on OFDM in its physical layer. The OFDM technique transmits data on closely spaced orthogonal subcarriers, and can increase the bandwidth efficiency. Fig. 4 shows the packet structure of the IEEE 802.11p. It is essentially the same as that of the IEEE 802.11a except for the doubled symbol duration. It has a preamble field, then a SIGNAL field and a number of data fields. At the end of the preamble, a symbol is started at a pre-determined magnitude and phase level. The preamble is used for synchronisation and channel equalisation The

SIGNAL field is sent using BPSK and contains information about the length, modulation type and data rate. Several OFDM Symbols with this input data bits then the number of OFDM Symbols will be variable.

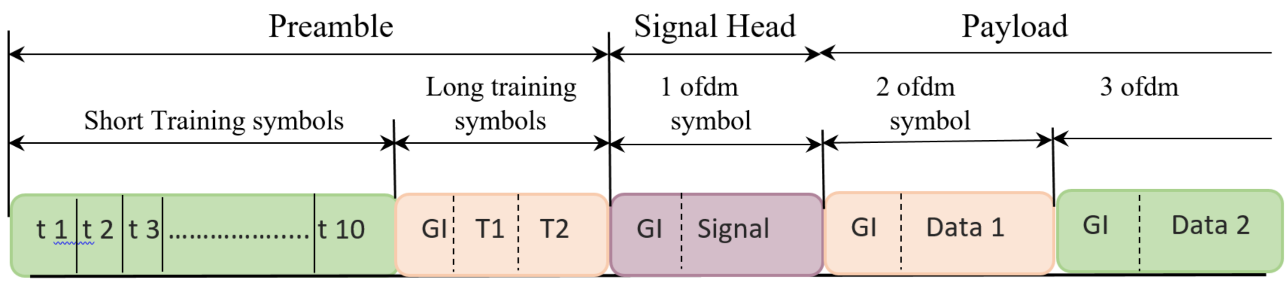


Figure 4. IEEE 802.11p Packet Format

The objective of applying OFDM technology is to convert the sequential data stream into parallel streams and that of applying IFT technique is to modulate these data onto orthogonal subcarriers. The IEEE 802.11 defines the configuration of one OFDM symbol as a total of 64 subcarriers. Useful subcarriers (data + pilot) numbered from -26 to 26 are referred to as 52 useful subcarriers. The pilot signals are coded on the subcarriers -21, -7, 7 and 21. The other 12 subcarriers are null carriers that are used in the beginning (0) and the middle (27-37) of the band to eliminate the effect of null carrier from the data subcarriers.

Null Carriers: In an OFDM symbol, N FFT subcarriers are not used for information bits mapping, but used for special purposes: N pilot subcarriers for pilot data transmission before decoding, N subcarriers in the middle of the symbol are null in frequency to avoid DC offset and N subcarriers at the edges of the symbol are null in frequency for out-of-band emissions avoidance [23]. Hence the number of data subcarriers can be calculated as;

$$N \text{ data carriers} = N \text{ FFT} - N \text{ pilots} - N \text{ guard} - N \text{ data carriers} \quad (8)$$

Although they make use of unused subcarriers, the overhead associated with unused subcarriers is

$$O \text{ unused} = N \text{ data symbol} * (N \text{ pilots} + N \text{ guard} + N \text{ data carriers}) \quad (9)$$

Few null carriers are utilised as pilots to prevent the overhead of unused carriers. Pilot based channel estimate in IEEE 802.11p. So that channel estimation is performed only once for one packet transmission. This technique could be suited for poor mobility situations. But if mobility is high, it may be necessary to have more channel information to assist with reliable linking of communication. Providing reliable communication links in vehicle environment is big task. The duration of the packet (time between channel estimations) can be short in order to maintain the quality of long range communications. Moreover, the node mobility may cause unfavourable effects on the communication. To overcome the coherence time condition we used more pilots to estimate the channel continually. For the Vehicular communication, the quality of the communication decreases with increasing the speed of the node. To counteract for the loss, a novel channel estimation technique based on the pilots will be proposed in the next part.

## 5 Methodology

### *A. Overall Methodology*

The proposed FCPCE method is based on the sequential OFDM transmission and channel estimate. Random data is generated and BPSK, QPSK, 16-QAM or 64-QAM is used to modulate it. Regularly inserted pilot. The acquired OFDM symbols are then IFFTed and cyclic-prefix added before transmitting them through the time varying vehicular channel in this case with AWGN. On the receiving end, cyclic prefix is removed and FFT is performed to get the frequency domain signal. The inserted pilots are retrieved for FCPCE based channel estimation and Bessel interpolation is used to estimate the channel response between pilot sites. Now the equalisation and demodulation is done using the estimated channel. Finally, the performance of the different modulation schemes and channel estimation algorithms are compared in terms of BER vs SNR.

### *B. OFDM-Based Vehicular Communication Model*

Vehicle communications are based on the proposed system that adopts the IEEE 802.11p OFDM physical layer. OFDM signal creation and recovery is achieved by using 64-point IFFT/FFT. BPSK, QPSK, 16 QAM and 64

QAM are used for the modulation of the data to be transmitted. A Cyclic Prefix is added before transmission to minimize Inter Symbol Interference. To simulate the dynamic and noisy nature of vehicular communication, the transmitted OFDM signal is modelled in time variable Rayleigh fading channel with AWGN. The cyclic prefix is eliminated at the receiver and FFT is employed to get the frequency domain signal for the subsequent channel estimate and data recovery.

### *C. Proposed FCPCE Pilot Arrangement*

The proposed FCPCE increases the pilot density than the conventional IEEE 802.11p scheme. The new idea is to periodically insert pilot symbols over the OFDM subcarriers, which provide more frequent channel information. The subcarriers are used for data transmission or are unused. A total of nine pilot subcarriers are located at 1, 8, 16, 24, 32, 40, 48, 56, and 64. This is because when the pilots are placed so frequently, a more continuous channel tracking can be achieved and the channel estimate performance can be enhanced in cases where the channel changes frequently, such as in vehicular environments, where the channel changes rapidly, possibly limiting the reliability of conventional pilot based channel estimation.

### *D. Channel Estimation and Bessel Interpolation*

At the receiver, we can remove the known pilot symbols and compare the received pilot values with the known symbols to get the channel coefficients at the pilot locations. All the subcarriers require the channel information and the coefficients at the non-pilot sites are interpolated by higher order Bessel interpolation. Since the pilots are dense and regularly spaced, there is more information to interpolate, and a more continuous estimation of the channel response over the OFDM subcarriers is thus possible. Then the channel estimates obtained are applied for further signal equalisation and recovery.

### *E. Receiver-Side Equalization*

Cyclic prefix is removed at the receiver and the received signal is transformed into the frequency domain via FFT. Next, the pilot symbols are recovered to obtain the channel response and the channel coefficients estimated over the subcarriers are obtained by using the FCPCE with Bessel interpolation. These estimates are then utilised to compensate the channel distortion and recover the transmitted OFDM signals. Recovered symbols from equalisation are demodulated to recover the original information data.

### *F. Experimental and Performance Evaluation Method*

The proposed FCPCE technique was also implemented using Python and then tested on a vehicular communication testbed consisting of five OBUs and one RSU with OBUs based on the Raspberry Pi 3 B+ board. Randomly generated data was passed between nodes via the wireless network and Wireshark was used to observe and analyse the transfer of packets. The performance of the suggested FCPCE method has been evaluated using QPSK and 16-QAM modulation and compared to that of the standard and New Combo-Pilot Estimation. The main performance measure was SNR versus BER to evaluate channel estimation and communication dependability.

## 6. Proposed Channel Estimation

In the present research effort, the proposed technique is based on the pilot symbols for the estimate of the channel. We propose a novel channel estimation named FCPCE, to enhance the performance of channel estimate in high dynamic time variation channels. The estimation is done using the more pilots as indicated in fig 5. In this case, pilots are fixed in a designed way periodically, to estimate the channel at regular intervals, preventing degradation of the communication channel often in a high dynamic nature.

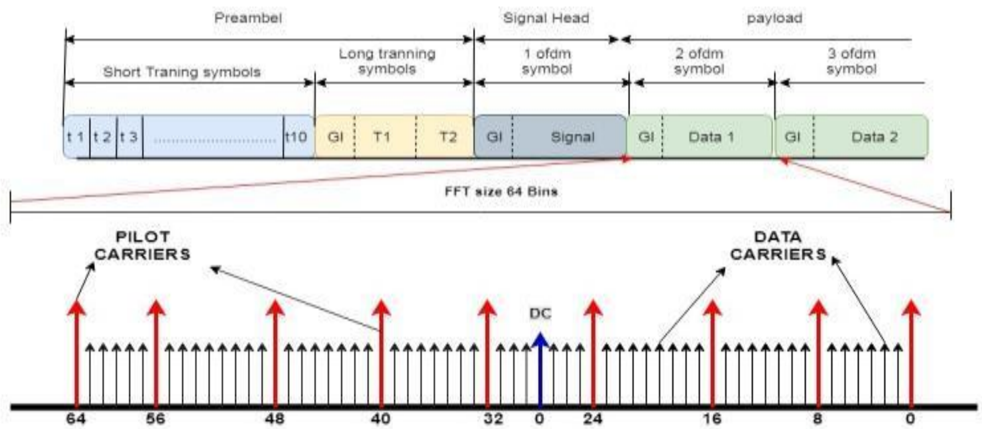


Figure 5. Proposed FCPCE Sub-carriers Assignment in OFDM

Channel Estimation is done as follows.

Step 1: We put the set of pre-defined signals (Normally, we refer to this as'reference signal' or 'pilot signal').

Step 2: Known signal travels through channel and is corrupted by other signals traveling through channel.

Step 3: We decode the received reference signal at the receiver.

Step 4: A comparison of the transmitted reference and received reference signals is performed and the correlation between the two is determined.

The proposed FCPCE scheme is to place the pilots frequently, even with the data subcarriers, for continually tracking the channel. The transmission procedure of the pilot symbol is rearranged and insertion of additional symbols is done. The OFDM symbol in FCPCE has 64 subcarriers, with 45 of them being data subcarriers and 9 being pilot subcarriers. 10 unused zero sub carrier / guard bands. The center , " DC " or " Null " . 9 pilot subcarriers are considered in one OFDM data block at 1, 8, 16, 24, 32, 40, 48, 56 and 64 places as shown in Figure 6 [6].

Channel Estimation: Channel Coefficient (between the transmitter and the receiver) Estimation. The recognised reference signals between the transmitter and receiver are the pilots. If we are at the pilot signals position, then we do know the channel coefficient. However, what we really need is channel coefficient at all the locations including the places where there is no pilot or “reference” signal. This implies that the coefficient of the channel has to be estimated there without any assistance from a reference signal. The most common approach we utilised interpolation to measure channel coefficient array. In this case, we used high order interpolation (Bessel) when the number of pilots is large and the pilots are regularly inserted, so we investigated the Bessel technique to get the channel coefficient without pilot value. A modified Bessel interpolation formula to estimate at pilots is used.

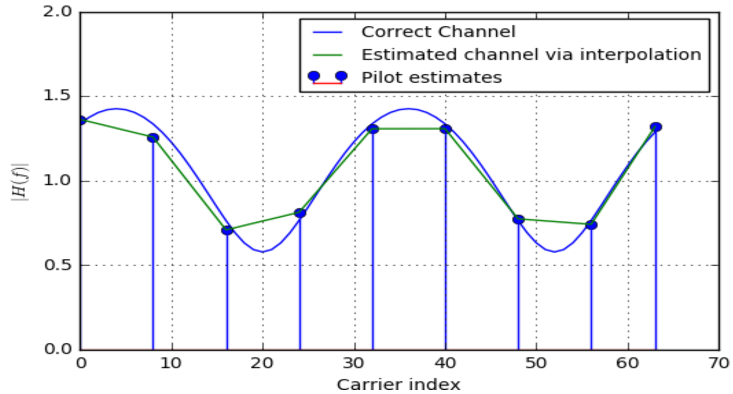

Figure 6. Estimated channel via interpolation

## 7. Experimental Setup and Result Analysis

The design of the transceiver has been developed for vehicular communication system to communicate between OBU's and RSU's by using python software with the novel FCPCE estimate technique. In physical communication channel estimation is performed at the receiver side which is used to decode the received signal and to reduce the distortion and noise in the channel at the receiver. The generic simulation parameter [2] was taken. Finally, the implementation of the system on Raspberry pi 3 B+ boards was done to verify the results.

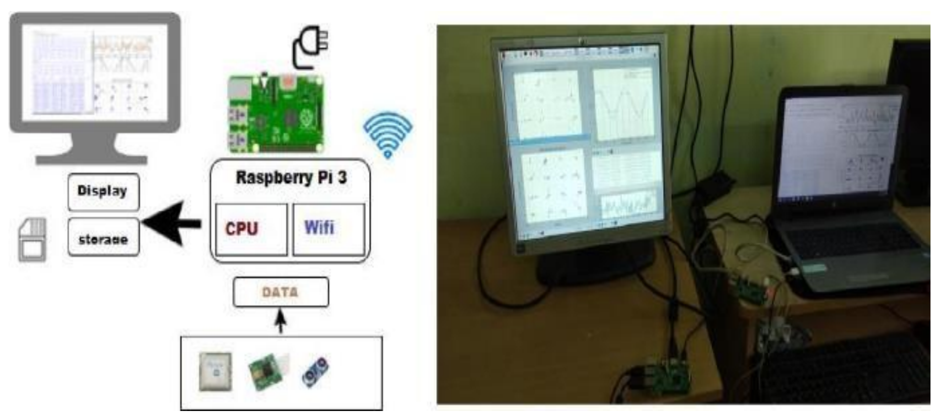

Figure 7. Design of OBU

The following were the technical specifications of the board:

a) 64 bit SBC 1.4 GHz Quad Core Processor

b) 5GHz wireless LAN

c) 1GB RAM

d) HDMI Full

e) 4 USB Ports

Figure 8. VANET Network Formation

Fig 8 is an experimental set up we prepare which consists of 5 nodes (OBU's) and 1 node (RSU). Each OBU is equipped with

1. Raspberry pi3 B+ board.
2. Power supplies
3. Wireless Internet (IEEE 802.11a, 2.4GHz & 5GHz Band)
4. Raspbian OS
5. Python 3.4
6. Wireshark 1.12 (Free & Open Source Pack Analyser)

Every OBU sent and received PN bits. In VANET, the Message transfers are presented in Fig. 9, the OBU's and the matching IP addresses are assigned.

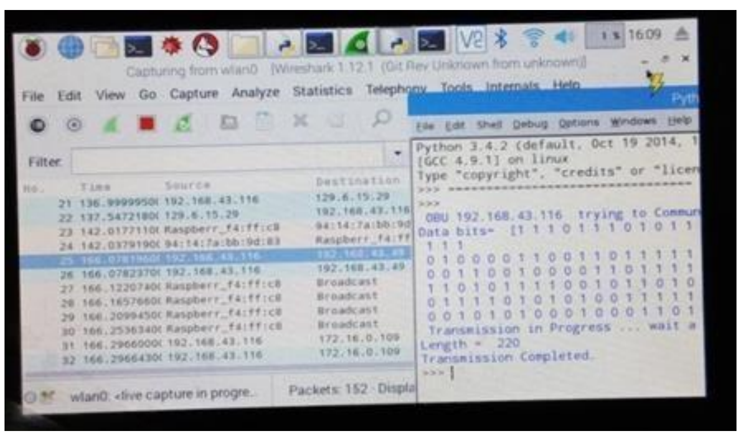


Figure 9. Received Packet Analyzer in Wire shark

One RUS node includes extra touch monitor display for configuration the packet data flow in the established network as shown in Fig.9.

Scenario 1: Setup of the Simple 5 node Vehicle Network.

The test data is broadcasted at the same time with the OBU1 with IP address of 192.168.43.116 (Source node) and the OBU3 with IP address of 192.168.43.46 (Destination node) receives the data, which can be monitored by Wireshark. All OBU and their corresponding IP Address as tabulated by Wi-Fi router.

Scenario 2: OBU 2 OBU communications shown in this experiment.

Vehicle 4 (OBU 4) with IP address, 192.168.43.56, sends message packets to Vehicle 2 (OBU 2) with IP address, 192.168.43.112. In this instance, the two displays are in two vehicles to observe the flow of the packet between the nodes in the network. One OBU 2 connected to an HP 15inch HDMI monitor to perform packet analysis and another OBU 4 with 3.5" touch screen display.

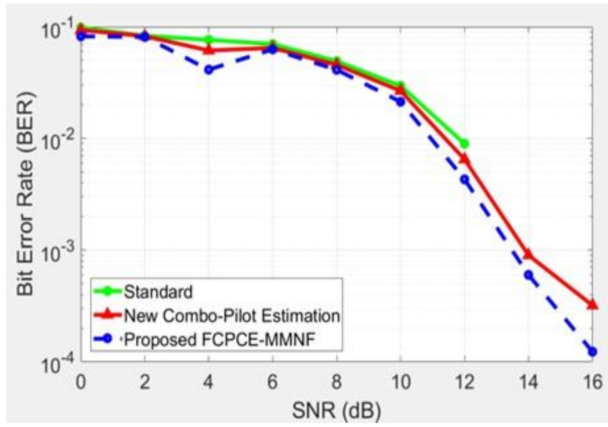


Figure 10. Impact of BER vs. SNR for QPSK

Node level analysis has been done for different channel equaliser techniques using Python. For comparative technique, the standard technique, new combo pilot and for proposed technique FCPCE we have analyzed the BER and SNR in the Fig 10 and Fig 11.

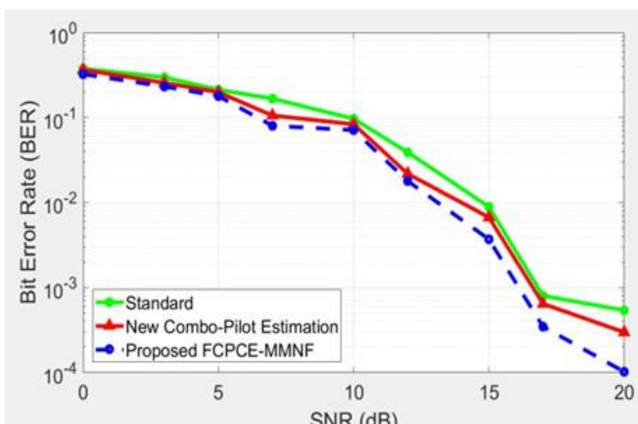


Figure 11. Impact of BER vs. SNR for 16 QAM

## 8. Conclusion

It can be seen from the result that at low SNR, standard methods have been able to reduce BER. The proposed method (FCPCE) however is much optimised having SNR of 30 dB when BER is low even at high modulation. In addition, this approach is easy to implement and does not require as much complexity as the other approaches for channel estimation. Thus, from the point of view of state-of-the-art techniques, FCPCE is the most efficient technique.

**References**


1. Hartenstein, H., & Laberteaux, K. P. (2008). “A tutorial survey on vehicular ad hoc networks.” *IEEE Communications Magazine*, 46(6), 164–171.
2. Mosleh, M. F. (2010). “Combination of LMS and RLS adaptive equalizer for selective fading channel.” *European Journal of Scientific Research*, 43(1).
3. Fernandez, J. A. (2012). “Performance of the IEEE 802.11p physical layer in vehicle-to-vehicle environments.” *IEEE Transactions on Vehicular Technology*, 61(1), 3–14.

4. Eichler, S. (2007). "Performance evaluation of the IEEE 802.11p WAVE communication standard." In *Proceedings of the IEEE Vehicular Technology Conference*.
5. Coleri, S., Ergen, M., Puri, A., & Bahai, A. (2002). "A study of channel estimation in OFDM systems." *IEEE Transactions on Broadcasting*, 48(3), 223–229.
6. IEEE Standard for Information Technology—Telecommunications and Information Exchange Between Systems—Local and Metropolitan Area Networks—Specific Requirements. (2010). *IEEE Standard 802.11p*.
7. Lin, Y., & Lin, J. (2010). "Novel channel estimation techniques in IEEE 802.11p environments." In *Proceedings of the IEEE Vehicular Technology Conference*.
8. Rappaport, T. S. (2002). *Wireless Communications: Principles and Practice*. 2nd ed. Prentice Hall.
9. Goldsmith, A. (2005). *Wireless Communications*. Cambridge University Press.
10. Bilstrup, K., Uhlemann, E., Strom, E. G., & Bilstrup, U. (2008). "Evaluation of the IEEE 802.11p MAC method for vehicle-to-vehicle communication." In *Proceedings of the IEEE Vehicular Technology Conference*.
11. Bai, F., & Krishnamachari, B. (2010). "Exploiting the wisdom of the crowd: Localized, distributed information-centric VANETs." *IEEE Communications Magazine*, 48(5), 138–146.
12. Gozalvez, J., Sepulcre, M., & Bauza, R. (2012). "IEEE 802.11p vehicle-to-infrastructure communications in urban environments." *IEEE Communications Magazine*, 50(5), 176–183.
13. Molisch, A. F. (2011). *Wireless Communications*. 2nd ed. Wiley-IEEE Press.
14. Bölcskei, H. (2006). "MIMO-OFDM wireless systems: Basics, perspectives, and challenges." *IEEE Wireless Communications*, 13(4), 31–37.
15. Li, Y. (2002). "Simplified channel estimation for OFDM systems with multiple transmit antennas." *IEEE Transactions on Wireless Communications*, 1(1), 67–75.
16. Edfors, O., Sandell, M., Van de Beek, J., Wilson, S. K., & Börjesson, P. O. (1998). "OFDM channel estimation by singular value decomposition." *IEEE Transactions on Communications*, 46(7), 931–939.
17. Paier, A., et al. (2009). "Characterization of vehicle-to-vehicle radio channels from measurements at 5.2 GHz." *Wireless Personal Communications*, 50(1), 19–32.
18. Abbas, T., Karedal, J., & Tufvesson, F. (2015). "Measurement based shadow fading model for vehicle-to-vehicle network simulations." *International Journal of Antennas and Propagation*.
19. Torrent-Moreno, M., Mittag, J., Santi, P., & Hartenstein, H. (2009). "Vehicle-to-vehicle communication: Fair transmit power control for safety-critical information." *IEEE Transactions on Vehicular Technology*, 58(7), 3684–3703.
20. Sassi, A., Tohme, S., & Artail, H. (2014). "Performance evaluation of pilot-based channel estimation for IEEE 802.11p vehicular communications." *International Journal of Vehicular Technology*.
21. Rohling, H. (1997). "OFDM: Concepts for future communication systems." In *Proceedings of the IEEE International Symposium on Personal, Indoor and Mobile Radio Communications*.
22. Van de Beek, J., Edfors, O., Sandell, M., Wilson, S., & Börjesson, P. (1995). "On channel estimation in OFDM systems." In *Proceedings of the IEEE Vehicular Technology Conference*.
23. Sepulcre, M., Gozalvez, J., Altintas, O., & Kremo, H. (2016). "Integration of congestion and awareness control in vehicular networks." *Ad Hoc Networks*, 37, 29–43.
24. Zheng, K., Zheng, Q., Chatzimisios, P., Xiang, W., & Zhou, Y. (2015). "Heterogeneous vehicular networking: A survey on architecture, challenges, and solutions." *IEEE Communications Surveys & Tutorials*, 17(4), 2377–2396.
25. Campolo, C., Molinaro, A., & Scopigno, R. (2015). *Vehicular Ad Hoc Networks: Standards, Solutions, and Research*. Springer.